A LABORATORY EVALUATION OF DETAIL REPRODUCTION, CONTACT ANGLE, AND TEAR STRENGTH OF THREE ELASTOMERIC IMPRESSION MATERIALS

by

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DEDICATION

This thesis is dedicated to my wife, Jie; my parents, Mr. Hong-tao Sun and Mrs. Ai-ping Sun, and my elder brother Dr. Wei Sun.
Their utmost devotion and unconditional love provided a solid basis for my completion of this thesis.

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INTRODUCTION

The technical complexity inherent in prosthodontic treatment has led to the utilization of an indirect approach in which the restoration fabrication is carried out extraorally. The completed restorations are subsequently placed into the oral cavity. The successful fabrication of indirect restorations largely depends on an accurate impression from which a replica of the intraoral structures can be precisely created. Although a number of materials and techniques have provided adequate clinical results, the ideal impression material has not yet been found.[1,2]

Elastomeric impression materials are currently one of the most popular options for definitive impressions in fixed prosthodontics.[3,4] Among available elastomeric materials in the market, the polyvinyl siloxanes and polyethers are used most frequently.[5]

Polyvinyl siloxane (PVS) was introduced as a dental impression material in the 1970s. PVS has also been labeled as vinyl polysiloxane impression material and as addition silicone. As a group, PVS comes with different viscosities and can accommodate several techniques. In contrast to the condensation silicones, these materials are dimensionally accurate because there are no by-products produced during the polymerization reaction. In addition, their adequate tear strength, dimensional stability, neutral odor, and taste make PVS materials the most widely used for making impressions.[1]

The major limitation of PVS is its hydrophobicity, which requires a dry environment for achieving an accurate impression. This characteristic is due to its chemical structure, which contains hydrophobic, aliphatic hydrocarbon groups

surrounding the siloxane bond.[6,7] Recently, some contemporary PVS materials have been modified with the addition of certain non-ionic surfactants and are described by the manufacturers as hydrophilic PVS materials. However, these modified PVSs are only slightly less hydrophobic than their predecessors[8,9] and the limited clinical advantage of this modification is to facilitate the pouring procedure.[1]

Polyether (PE) impression material was developed during the 1960s in Germany. Like PVS, no volatile byproduct is formed during the polymerization process, resulting in the excellent dimensional accuracy of this material.[2]

PE is often preferred by some clinicians because of its inherent hydrophilic nature and enhanced wettability. In contrast to PVS, PE possesses natural hydrophilicity because chemically it contains carbonyl (C=O) and ether (C-O-C) functional groups that attract and interact with water molecules through increased polarity.[6] This property facilitates contact of the unset material with moist intraoral tissues and structures as well as the wetting of the polymerized impression by the cast material.[10]

However, PE has several shortcomings. The stiffness of the polymerized PE is one of them.[7] When a stone cast is separated from the impression, in situations where a practitioner has to take an impression of a thin, single tooth, the die stone is prone to breakage.[1]

Efforts to overcome the disadvantages have been made in the most recently developed PE. By decreasing the filler ratio to render a less rigid impression, the difficulties of removing the impression from a patient's mouth and separating impressions from casts can be reduced, especially in cases with significant undercuts. Another approach to reduce the stiffness of the polymerized material is by adding low-

viscosity softeners.[10] However, the attempts to reduce the stiffness have helped only to a certain extent, and proper undercut blockout is still necessary in most cases.

In order to take advantage of the properties of both PVS and PE impression materials, a new generation of impression material, called vinyl polyether silicone (VPES, GC) is being developed. According to the information provided by the manufacturer, the platinum-initiated vinyl siloxanether consists of a copolymer of α,ω-divinyl polydimethylsiloxane and α,ω-divinyl polyether cross-linked by an organo hydrogen polysiloxane. The composition is intended to incorporate the natural hydrophilicity and flowability of conventional PE materials along with the desirable properties of PVS materials, such as elastic recovery, tear strength and dimensional accuracy and stability.[11] The potential advantages of a recently marketed VPES are: 1) intrinsic hydrophilicity without using surfactants; 2) handling characteristics similar to PVS; 3) high tear strength with flexibility; 4) predictable subgingival flowability, and 5) a mild mint taste.

Detail reproduction, contact angle, and tear strength are critical parameters for an impression material and are claimed to be remarkable characteristics of VPES. A review of the literature shows there are limited data on the detail reproduction, contact angle, and tear strength of this new generation of impression material, VPES. The comparable data of VPES on these clinical parameters would be important references for clinical application. Therefore, the objective of this study was to compare the detail reproduction, contact angle, and tear strength of this recently developed VPES with representative hydrophilic PVS and PE in common clinical use.[1,7,12]

The hypotheses of this research were: 1) VPES would show a significant superiority in surface detail reproduction compared with PVS and PE impression materials; 2) VPES would show a significant superiority in wettability compared with PVS and PE impression materials, and 3) VPES would show a significant superiority in tear strength compared with PVS and PE impression materials.

REVIEW OF LITERATURE

DETAIL REPRODUCTION

The detail reproduction of impression materials plays a major role in determining how accurately various indirectly produced appliances and restorations may be constructed. Clinically, the accuracy transferred by impressions from the intraoral structures to the final restorations depends on two major aspects: 1) the ability of the impression mix to flow and adapt intimately to the relevant surfaces while making the impression, and 2) the wetting of the polymerized impression material by the gypsum when pouring the impression.[13] The international standard for dental elastomeric impression materials states that a light body impression material must reproduce a line 0.020 mm in width.[47] As matter of fact, with the exception of very high viscosity putty materials, all PVS products can achieve this requirement. The very low viscosity PVS can even reproduce lines 1 μm to 2 μm wide under laboratory conditions.[13]

However, the accessibility of an ideal detail reproduction under a moist clinical condition is challenging and many factors are involved.[16] The ability of materials to record detail on moist tissue surfaces was related to both the wettability and rheological properties.[17]

When considering the intimate contact between unset impression material and the target surfaces, the influences from blood, saliva or other liquids may be significant because these liquids can push away the inherently hydrophobic elastomeric materials and form defects in critical intrasulcular areas.[8,9] The inherent hydrophilicity of PE accounted for its superior behavior in moist conditions and, likewise, it was believed that

the poor detail reproduction with PVS was due to its inherent hydrophobicity.[12] Currently, studies on detail reproduction have focused on the influence of moist conditions and how to improve the wettability of these hydrophobic elastomeric materials.[18,19]

To overcome the distinct hydrophobicity of conventional PVSs, manufacturers incorporated the surfactants. Most commonly, these surfactants consist of an oligoether or polyether substructure as the hydrophilic component.[20] For instance, nonylphenoxypolyethanol homologues are examples one of these molecules[12,21-23] that can diffuse into the liquid phase of the plaster and reduce its surface tension and increase the surface energy of set impression materials. As a result, the wettability of the impression materials were improved.[24]

Walker et al.[19] evaluated and compared the detail reproduction of two hydrophilic PVS and two PE impression materials when applied under dry and moist conditions (using a uniformly applied fine mist of water). The PE showed better surface detail than the hydrophilic PVS even though adverse effects were found with both impression materials under moist conditions.

Johnson studied the effect of moisture on the detail reproduction of PE and hydrophilic PVS by assessing the roughness of the impression.[16] The impressions were made of a surface analyzer calibration standard possessing a uniform saw-tooth pattern. The surface of each impression was scanned by a Surfanalyzer 4000. The result demonstrated that the PE showed better detail reproduction than PVS even though moisture led to less detail reproduction in both materials.

Besides the wettability, rheological properties of impression materials are considered to be crucial in detail reproduction. Peutzfeldt and Asmussen[18] reported a significant negative correlation between the water-displacing ability of impressions and the contact angle formed between water and impression materials as long as the contact angle was less than 70°. It was found that for materials with a contact angle larger than 70°, the viscosity was the deciding factor for water displacement.

Elastomeric materials possess significant differences in rheological properties.[25-28] Chee and Millar[15,19] studied the relationship between viscosities and detail reproduction of elastomeric impression materials. They found that when various viscosities of impression materials were compared, the detail reproduction was different from material to material and batch to batch.[18] Both PVSs and PEs can be manufactured with low viscosity to encourage detail reproduction but it has been shown that there is a significant difference in rheological properties of these materials during the period shortly after mixing.[32,34] In McCabe's study, the rheological properties of four materials, three PVSs and one PE, were determined using a controlled-stress rheometer.[31,32,33,35] The results showed that the polyether material, which is the most hydrophilic of the materials[23] and one of the polyvinylsiloxanes (Aquasil) are accurately able to reproduce deep grooves on moist surfaces. The other silicone products are not so reliable for this purpose. Interestingly, the polyvinylsiloxanes (Aquasil) has a very similar rheological value to Impregum immediately after mixing but unlike Impregum, the value of Aquasil decreases rapidly indicating that a more elastic nature is quickly developed.[36] Aiasha compared the detail reproduction in PE and hydrophilic PVS. The result demonstrated that medium

body PE reproduced better details than that of light body PE under wet conditions. This suggests that the viscosity is an important factor involved in detail reproduction.[37]

Other studies have demonstrated that there are other factors that influence detail reproduction, such as rate of setting, depth of penetration or fluidity, and handling characteristics are important features for detail reproduction.[13,29,30,38] However, other aspects are less controversial with hydrophilicity being most critical factor under moist clinical conditions.[8,9]

WETTABILITY

Wettability is defined as the degree of spreading of a liquid drop on a solid surface and thus describes the affinity of a liquid for a solid. Materials which are termed "hydrophilic" have a large affinity for and are readily wetted by water.[13] The wetting behavior of elastomeric impression materials during setting is regarded as a key factor that affects the wetting of oral soft and hard tissues and therefore the accurate detailed reproduction of prepared tooth surfaces and influences the capacity of the set material to be poured with gypsum slurries without trapping air bubbles.[20,41]

The surface quality of the die stone casts is directly related to the wettability of impression materials. Also the gypsum castability results had good agreement with the data from the wettability test. The condensation silicone and the conventional addition silicones produced die stone casts with higher number of voids than the hydrophilic silicones and the polyether materials. These findings further confirm previous suggestions on the relation between the wettability of impression materials and air bubble entrapment.[9]

By adding intrinsic surfactants to the bulk material, conventional hydrophobic PVS materials have been developed with improved wetting behavior and these new hydrophilized formulations are more readily poured up with a gypsum-based die stone.[42,43] Vassilakos and Fernandes[44] evaluated the wettability of hydrophilic PVS, condensation silicone, and PE and their gypsum castability. They found that the condensation silicones and conventional PVS exhibited the largest contact angles and had the highest number of voids. The hydrophilic PVS has higher wettability than the conventional silicones.

Pratton and Craig[9] studied the wettability of a hydrophilic PVS material. They compared the wettability of hydrophilic PVS with PE, polysulfide, and hydrophobic PVS by measuring the contact angle of a saturated aqueous solution of $CaSO_4$ on the impression materials with a telescopic goniometer. The wettability of the hydrophilic PVS impression material in this study was found to be not significantly different from that of a polyether impression material and both were the best among the experimental groups.

Other methods to improve the wettability of materials with inherently hydrophobicity have been reported. It has been shown that topically applied surfactants[45] and disinfectants[9] may increase the wettability of elastomeric impression materials. However, these results have been obtained for bare impression surfaces and need to be confirmed in studies that take into consideration the presence of adsorbed salivary films. Also the effect of these treatments on other properties of impression materials such as dimensional stability has not yet been fully investigated. Radiofrequency glow discharge

is another method which has been recently described to considerably increase the wettability of elastomeric materials with original low surface energy.[46]

However, there is no scientific evidence to indicate that PVSs advertised as hydrophilic can be syringed into a wet sulcus for an accurate impression.[1,9,47] Millar et al.[48] reported a significant reduction in the number of voids and an overall increased quality of polyvinyl siloxane impression when a modified polydimethyl siloxane wetting agent was applied to the prepared tooth surfaces before impressions were made.

Contact angle measurements are typically conducted on fully set materials. However, more and more studies have been focusing on the wettability of unset impression materials. It has been found that the wettability of the impression materials will change during the setting reaction and it is the wettability during the early, viscous phase of the setting reaction that is most likely to govern the quality of the final impression.

Mondon and Ziegler[39] assessed the changes in wettability of dental impression materials during setting. They compared the properties of the initial water contact of two different dental impression materials and their subsequent hydrophilic development during polymerization. PE and PVS were tested in this study. They concluded that PE showed a more hydrophilic behavior during the process of setting compared to hydrophilic PVS.

In a study of Chai et al.,[22] the contact angles of PE, hydrophilic PVS, conventional PVS, and PVS putty were recorded in a real time pattern. Contact angles were measured at different time intervals after the start of mixing. They found that varying the time after the start of mixing did affect the wettability of the experimental

impression materials. The study concluded that the wettability of an unset or setting impression material was more relevant to clinical practice.

In summary, the modification of conventional or hydrophobic PVS by adding a surfactant was shown to improve its wettability.[22,44] However, when compared with PE, some studies concluded that hydrophilic PVS had better wettability[22,39,40] while others have shown that PE has better wettability than hydrophilic PVS.[9,44]

TEAR STRENGTH

The tear of elastomeric materials is a mechanical rupture process initiated and propagated at a site of high stress concentration caused by a cut, defect, or localized deformation.[42] Tear strength indicates the resistance of a material to fracture when it is subjected to a tensile force acting perpendicular to a surface flaw. An impression material must have sufficient strength to allow removal from the gingival sulcus without tearing, which is of obvious importance in thin intrasulcular or interproximal areas. It has been reported that some impression material remnants remaining in the sulcus may produce inflammation reactions.[25,26] Thus, the tear strength of candidate impression materials is an important parameter for clinicians.[26,49]

The clinical tear performance of a material involves complex interactions between polymer and fillers, flow to a particular film thickness, release properties from tooth and soft tissue, the presence of internal and surface defects, and the rate of impression withdrawal. Because of the complexities of integrating and measuring these properties, laboratory tests evaluating the propagation energy of a tear have been employed as common ways to evaluate elastic dental materials.[35,50-52] Many studies on tear strength have been carried on; however, standardized test methods have not been established.[53-55]

As a result, comparisons between different impression materials with available data is difficult.[2,56]

The trouser tear test, the most commonly used method to assess tear strength, was pioneered by Griffith (1920) and developed by Rivlin and Thomas.[57] They introduced the simple extension tear test piece, which was later adapted to the trouser tear test of dental impression material by Webber and Ryge.[35] This method was standardized and described by American Society for the Testing of Materials D 624-91.[53] Braden [58,59] employed this approach to evaluate the tear strengths of a silicone, a polysulfide, and an irreversible hydrocolloid impression material. The results showed that the polysulfide rubber was twice as strong as the silicone system, which in turn was twice as strong as the irreversible hydrocolloid. He also found that increased tear rates resulted in greater tear strengths.

Sneed[54] investigated the tear strength of polysulfide, condensation silicone, PE, and PVS by this modified simple extension tear test. The specimens were extended in a universal testing machine to test the tear strength. They found that the tear strength of PE was higher than that of the addition or condensation silicones.[2,35]

Tear energy, or the energy required to sustain a tear through a material, is another parameter to assess tear strength of impression materials.

Chai et al.[2] studied the tear energy of elastomeric impression materials and the tear energy was calculated from the results of a standard trouser tear on 10 specimens of each impression material. The result showed that the tear energy of PE was higher than PVS, which was consistent with the result of tear strength study.

Huan et al.[51] compared tear energy (J/m2) and elastic recovery (%) for two addition silicone impression materials and a polyether material following Webber and Ryge's method and ASTM D412 (Test Method A), respectively. The data demonstrated that PE impression materials had higher tear energy in compression and lower elastic recovery compared to new hydrophilic addition silicone materials. Heavy-body materials had higher tear properties than light-body materials.

From the standpoint of clinical application, materials with high tear energy or tear strength are not necessarily considered to be superior to the materials with low tear energy or tear strength. The ideal impression material should exhibit maximum energy absorption with minimal distortion. However, it is also desirable that the material tears rather than deforms past a critical point such as a margin. PVSs deform at much slower rates and tear at points of less permanent deformation than do the other elastomeric materials. They can absorb over three times more energy up to the point of permanent deformation than other elastomers, and if elongated to over 100 percent (strain at tear), they rebound to only 0.6-percent permanent deformation.[55,60]

The other aspects that relate to tear strength have been investigated. Lawson et al.[61] measured the tear strength of PVS, PE, and hybrid addition silicone/polyether at different setting times and different tearing rates. They found that the tear strength increased with increased setting time and at increased tearing rates. Vrijhoef and Battistuzzi[62] found that there was considerable overlap of the tear strength values among the materials within the material groups tested.

MATERIALS AND METHODS

The detail reproduction, contact angle, and tear strength of hydrophilic PVS, PE, and VPES were evaluated. All the materials were extruded from double-chamber cartridges through static mixing tips (Figure 1) provided by the manufacturer. The description of impression materials are shown in Table I. The testing groups and sample size are shown in Table II.

DETAIL REPRODUCTION TEST

The test was done following the International Standards Organization (ISO) Standard 4823 for elastomeric impression materials with minor modifications.[54] According to ISO 4823, stainless steel dies scored with three horizontal lines (20 µm, 50 µm, 75 µm) and two vertical lines are designed for use in making impressions. This study used a stainless steel block with the dimensions of 38 mm × 6 mm × 6 mm. (Figure 4) The test block had a series of 15 lines and each line varied in width from 1 µm to 50 µm and each line was assigned a number. The line with 20 µm was used as the critical point to pass or fail a specimen, as delineated within the ISO 4823. The widths of the lines in micrometers were: 1) 50 µm; 2) 46 µm; 3) 40 µm; 4) 34 µm; 5) 20 µm; 6) 18 µm; 7) 16 µm; 8) 12 µm; 9) 8 µm; 10) 4 µm; 11) 3 µm; 12) 2 µm; 13) 2 µm; 14) 1 µm; and 15) 1 µm. (Figure 5).

Specimen Preparation

Specimen preparation was completed as described by Estafanous.[63] Special trays from Triad True Tray light-cure custom tray material (Dentsply, St. Charles, MO) with a

3-mm relief for the impression material were used for making the impression (Figure 2). This technique helped to minimize the amount of required impression material and aided in the removal of the material from the test block.

The moist condition was achieved by applying a fine mist of water from a spray bottle to the surface of the test block before applying the impression material onto it. Care was taken to ensure that the entire test block was covered with a uniform mist of water, avoiding any excess or beading.[21,51] The custom trays were painted with tray adhesive following the manufacturer's recommendations for each impression material being used. Then, an increment of the mixed materials (enough to slightly overfill the surface of the block) was introduced onto the surface of the tested block and inside the custom tray; pressure was applied using a 20-lb weight to facilitate the material's flow into the lines (Figure 3). Sixty seconds after completion of the mix, the specimen-forming assembly was placed in a 37°-C incubator to simulate the oral temperature and left for double the setting time recommended by the manufacturer's instructions. This ensured the complete setting of the impression material. Twenty specimens of each material were prepared; 10 for the moist condition and 10 for the dry condition.

The reproduction of line 5 (20 µm) was taken as a minimum requirement to pass the specimen. Any inability to reproduce this line or the appearance of any voids that exceeded the width of each line was registered as a failure. The data were analyzed by utilizing a Chi-square test for pass/fail, and a two-way ANOVA evaluation for the number of lines and the width of lines reproduced. The variables of material and condition (dry, moist) were evaluated for pair-wise comparisons using Fisher's protected least significant differences.

Wettability Test

A Duralay mold of dimensions 100 mm ×15 mm × 1 mm was used to produce rectangular samples from the materials to be tested. Twenty-five samples were produced from each impression material. Care was taken not to permit contamination of the material samples. All the samples were mixed, stored, and analyzed at 21°C ± 2°C and 50% ±10% relative humidity.[64]

The Pocket Goniometer, PG-2 (UV Process Supply, Inc., Chicago, IL) was employed to measure the contact angle. Three drops (0.05 ml) of a saturated solution of $CaSO_4$ in double distilled water were then dispensed on the test surface (Figure 6). The drops were allowed to reach equilibrium for 5 seconds and the contact angles were automatically measured by the Pocket Goniometer, PG-2. The mean of the three drops was used for further analysis of the data. The three impression materials were tested separately.

Tear Strength Test

Test mold: A Duralay slab (Figure 7) with a relieved rectangle 25 mm × 75 mm × 1 mm was used as a mold.[35,65]

Specimen preparation: In accordance with Sneed and ASTM (the American Society for Testing and Materials) recommendations,[69] the specimens were mixed at room temperature (21°C ± 2°C) according to the manufacturer's instructions and were injected inside the test mold. A glass slab then was used to flatten the specimen. Thirty specimens of each material were made. Fifteen samples were incubated at 37 °C to simulate the intraoral temperature and were tested 10 min after setting. The other 15

samples were incubated at 24 ℃ to simulate a typical office temperature and were tested 24 hours after setting.[61]

Test procedure: The thickness of each sample was measured with a Mitutoyo Digimatic CD-6 vernier caliper with a digital readout (Mitutoyo, Kawasaki, Japan). Measurements were made in three places: at the two ends and in the middle of each specimen. The mean thickness was then calculated. The tear test pieces were prepared by making a 50-mm long cut with a #11 scalpel by using a single stroke at the center of the 25-mm side of the test specimen, and this delineated the two grip areas.[35,65] The specimens were placed in the Instron Universal Testing Machine (Instron Corp., Canto, MA). The ASTM recommended rate of jaw separation of 50±5 mm/min was used in this part of the study. The specimens were strained until rupture (Figure 8).

The tear strength T_s was calculated by the formula $T_s = F/d$ where F was the force in Newton (N) and d was the mean thickness of each specimen in millimeters (mm).[20] The data were analyzed by using a one-way ANOVA with a factor for material, followed by pair-wise comparisons using Fisher's protected least significant differences.

SAMPLE SIZE JUSTIFICATION

The within-group standard deviations were estimated to be 0.1 N/mm for tear strength,[55] 0.36 μm for detail reproduction,[16] and 6° for contact angle.[23] All sample size calculations assumed an 80-percent power and the two-sided tests were conducted at a 5-percent significance level. The study of detail reproduction with a sample size of 10 samples per treatment combination (dry and moist conditions) detected a detail reproduction difference of 0.48 μm; the study on tear strength with a sample size of 15 samples detected a tear strength difference of 0.066 N/mm; the study on contact angle

with a sample size of 25 samples detected a contact angle difference of 4.85°. The testing groups and sample sizes are shown in Table II.

RESULTS

DETAIL REPRODUCTION

Detail reproduction as measured by both the number of lines, and the width of the lines was significantly greater for dry samples than for moist samples ($p < 0.0001$). When detail reproduction was assessed using the number of lines reproduced (Table III, III (i), Figure 9) dry-sample PE reproduced fewer lines than PVS ($p = 0.0005$) and VPES ($p = 0.0001$) with no difference between dry-sample PVS and VPES ($p = 0.58$); but, there were no significant differences among the three materials for the moist samples ($p = 0.43$). When detail reproduction was assessed using the width of the lines (Table IV, IV (i), Figure 10) there were no significant differences among the three materials ($p = 0.41$). The proportion of specimens passing the detail reproduction test was higher for dry than moist for PVS ($p = 0.0034$) and VPES ($p = 0.0253$), but they did not reach significance for PE ($p = 0.06$); no differences were found among materials for dry ($p = 1.00$) or moist ($p = 0.39$) samples (Table V).

CONTACT ANGLE

Contact angle was significantly higher for PE (54.76) than VPES ($p < 0.0001$) and PVS ($p < 0.0001$) and higher for VPES 44.84º than PVS 34.19º ($p < 0.0001$), as shown in Table VI, VI (i) and Figure 11.

TEAR STRENGTH

Tear strength was significantly higher for PE than PVS ($p < 0.0001$) and VPES ($p < 0.0001$) and higher for PVS than VPES ($p = 0.0006$). Tear strength at 24 hour was significantly higher than 10 minutes ($p = 0.0371$) (Table VII, VII (i), Figure 12).

TABLES AND FIGURES

TABLE I

Impression materials tested

Test impression materials	**Manufacturer**	**Setting Time**	**Batch No.r**
Aquasil XLV (hydrophilic, polyvinyl siloxane)	Dentsply Corp. Germany	5 min	#030225
Impregum Soft Light Body (polyether)	3M ESPE, St. Paul, MN	4 min	# B126754
Exa'lent light body (vinyl polyether silicone)	GC Corp, USA	5 min	#0457854

TABLE II

Testing groups and sample sizes

Test \ Impression materials	Conditions	VEPS	PE	PVS
Tear Strength (N/mm)	10 min (37°C)	15	15	15
	24 h (24°C)	15	15	15
Detail Reproduction	Dry	10	10	10
	Moist	10	10	10
Contact Angle	21°C	25	25	25

TABLE III

Number of lines of detail reproduction

	Material	Condition	N	Mean (SD)	Min	Max
Lines	PE	Dry	10	**11.30 (0.95)**	10	13
		Moist	10	6.00 (1.56)	4	8
	PVS	Dry	10	12.70 (0.67)	11	13
		Moist	10	5.00 (1.83)	3	8
	VPES	Dry	10	12.90 (0.74)	12	14
		Moist	10	5.80 (1.99)	3	9

Max = maximum; Min = minimum; SD = standard deviation; D = dry condition; M = moist condition.

TABLE III (i)

Number of lines of detail reproduction (two-way ANOVA)

Conditions	Comparisons	P values
Polyether	Dry vs. moisture	p < .0001*
Polyvinyl siloxane	Dry vs. moisture	p < 0.0001*
Vinyl polyether silicone	Dry vs. moisture	p < 0.0001*
Dry condition	Polyether vs.vinyl polyether silicone	p = 0.0001*
	Polyether vs. polyvinyl siloxane	p = 0.0005*
	Vinyl polyether silicone vs. polyvinyl siloxane	p = 0.58
Moist condition	Polyether vs. vinyl polyether silicone	p = 0.43
	Polyether vs. polyvinyl siloxane	p = 0.43
	Vinyl polyether silicone vs. polyvinyl siloxane	p = 0.43

*Statistically significant differences.

TABLE IV

Width of lines of detail reproduction

	Material	Condition	N	Mean (SD)	Min	Max
Width (µm)	PE	Dry	10	2.80 (0.79)	2	4
		moist	10	21.20 (9.10)	12	34
	PVS	Dry	10	2.10 (0.32)	2	3
		moist	10	27.80 (10.93)	12	40
	VPES	Dry	10	1.80 (0.42)	1	2
		moist	10	23.00 (11.28)	8	40

Max = maximum; Min = minimum; SD = standard deviation; D = dry condition; M = moist condition.

TABLE IV (i)

Width of lines of detail reproduction (two-way ANOVA)

Conditions	Comparisons	P-values
Polyether	Dry vs. moisture	$p < 0.0001$*
Polyvinyl siloxane	Dry vs. moisture	$p < 0.0001$*
Vinyl polyether silicone	Dry vs. moisture	$p < 0.0001$*
Dry condition	Polyether vs. Vinyl polyether silicone	$p = 0.41$
	Polyether vs. polyvinyl siloxane	$p = 0.41$
	Vinyl polyether silicone vs. polyvinyl siloxane	$p = 0.41$
Moist condition	Polyether vs. vinyl polyether silicone	$p = 0.41$
	Polyether vs. polyvinyl siloxane	$p = 0.41$
	Vinyl polyether silicone vs. polyvinyl siloxane	$p = 0.41$

*Statistically significant differences.

TABLE V

Pass rate of detail reproduction

	N (%) Pass		Statistically Significant Differences (Chi-square tests)
Material	Dry	Moist	
PE	10 (100)	7 (70)	No significance (p = 0.06)
PVS	10 (100)	4 (40)	D — M (p = 0.0034)
VPES	10 (100)	6 (60)	D — M (p = 0.0253)

D= dry condition; M = moist condition.

TABLE VI

Wettability – contact angles

Material	N	Mean (SD)	Min	Max
PE	25	54.76 (4.03)	50.3	62.1
PVS	25	34.19 (4.73)	24.3	41.4
VPES	25	44.84 (1.69)	40.5	47.6

Max = maximum; min = minimum; SD = standard deviation.

TABLE VI (i)

Wettability – contact angles (One-way ANOVA)

Comparisons	P-values
Polyether vs. Vinyl polyether silicone	$p < 0.0001$*
Polyether vs. polyvinyl siloxane	$p < 0.0001$*
Vinyl polyether silicone vs. polyvinyl siloxane	$p < 0.0001$*

*Statistically significant differences.

TABLE VII

Tear strength

Material	Time	N	Mean (SD)	Min	Max
PE	10 min	15	0.73 (0.14)	0.566	1.016
	24 hr	15	0.87 (0.23)	0.482	1.478
PVS	10 min	14	0.36 (0.08)	0.217	0.507
	24 hr	15	0.37 (0.06)	0.25	0.477
VPES	10 min	15	0.30 (0.08)	0.22	0.495
	24 hr	15	0.31 (0.03)	0.247	0.38

Max = maximum; Min = minimum; SD = standard deviation.

TABLE VII (i)

Tear strength (two-way ANOVA)

Conditions	**Comparisons**	**P-values**
10 min	Polyether vs. vinyl polyether silicone	$p < 0.0001$*
	Polyether vs. polyvinyl siloxane	$p < 0.0001$*
	Vinyl polyether silicone vs. polyvinyl siloxane	$p = 0.0006$*
24 h	Polyether vs. vinyl polyether silicone	$p < 0.0001$*
	Polyether vs. polyvinyl siloxane	$p < 0.0001$*
	Vinyl polyether silicone vs. polyvinyl siloxane	$p = 0.0006$*
Polyether	10 min vs. 24 h	$p = 0.0371$*
Polyvinyl siloxane	10 min vs. 24 h	$p = 0.0371$*
Vinyl polyether silicone	10 min vs. 24 h	$p = 0.0371$*

*Statistically significant differences.

FIGURE 1. Auto-mix gun (PE) for the test.

FIGURE 2. Customer tray for detail reproduction test.

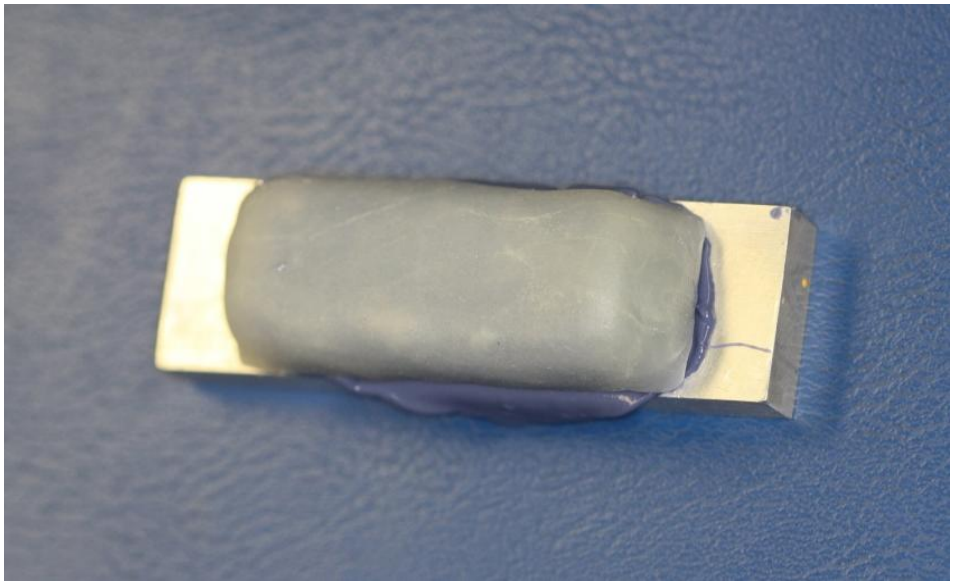

FIGURE 3. Making impression for detail reproduction test.

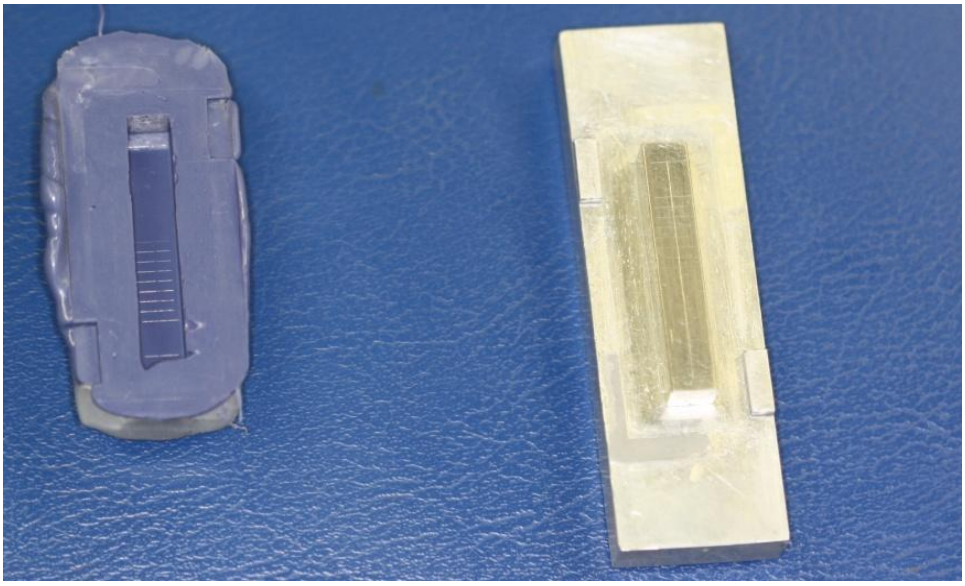

FIGURE 4. Impression and metal mold for detail reproduction test.

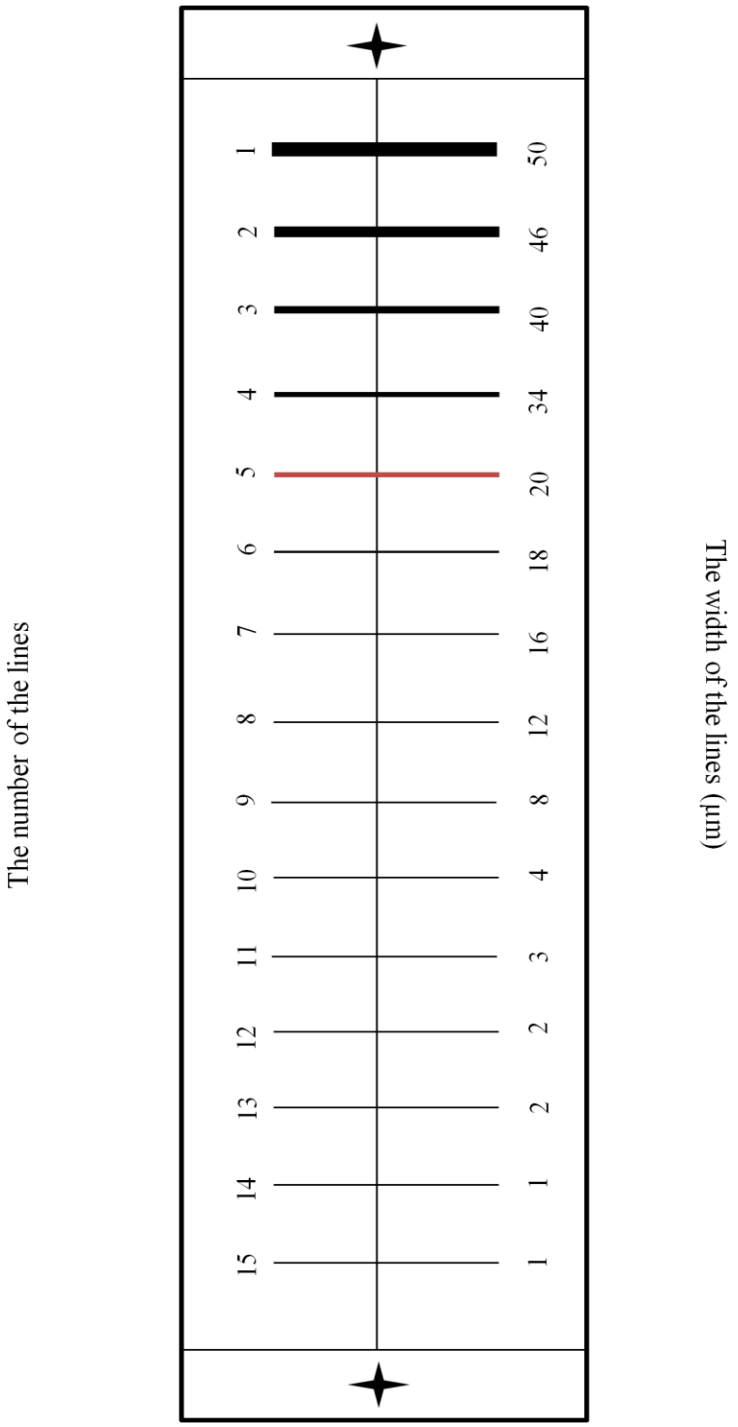

FIGURE 5. Diagrammatic illustration of the upper surface of the master metal.

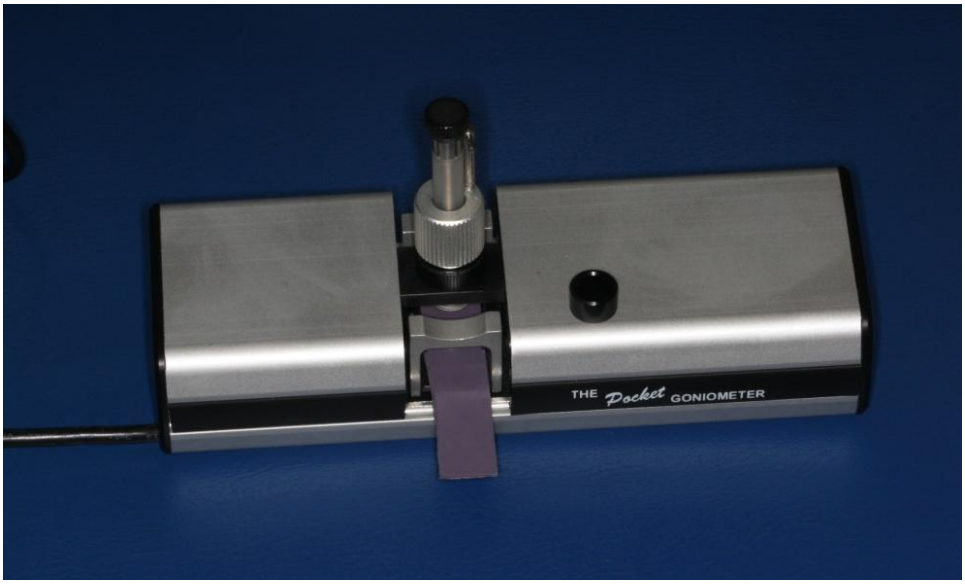

FIGURE 6. The Pocket Goniometer PG-2.

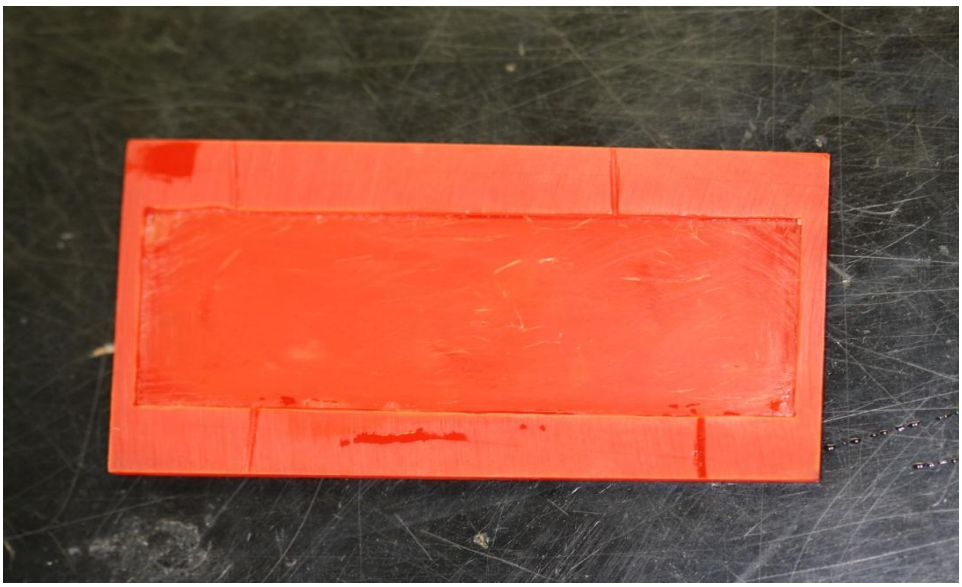

FIGURE 7. Duralay mold for tear strength test.

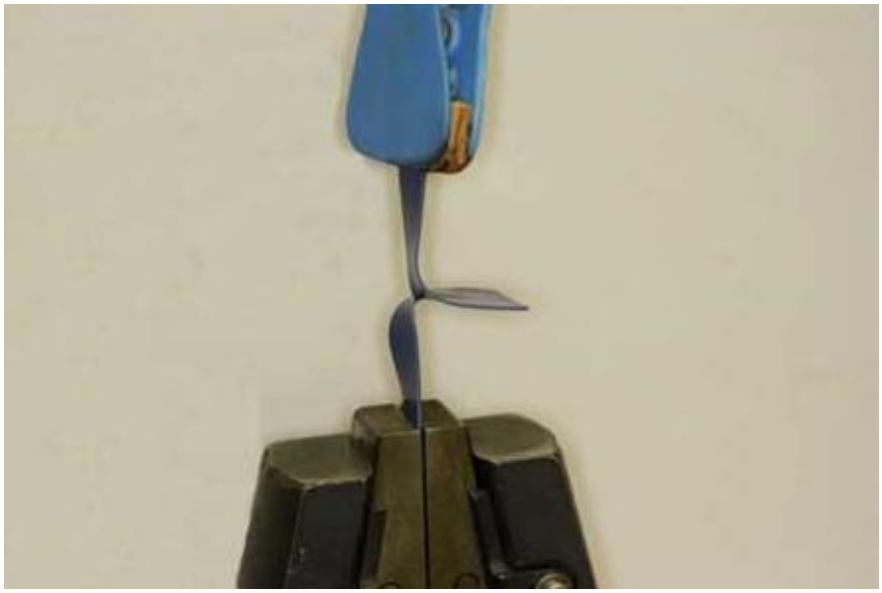

FIGURE 8. Tear strength test.

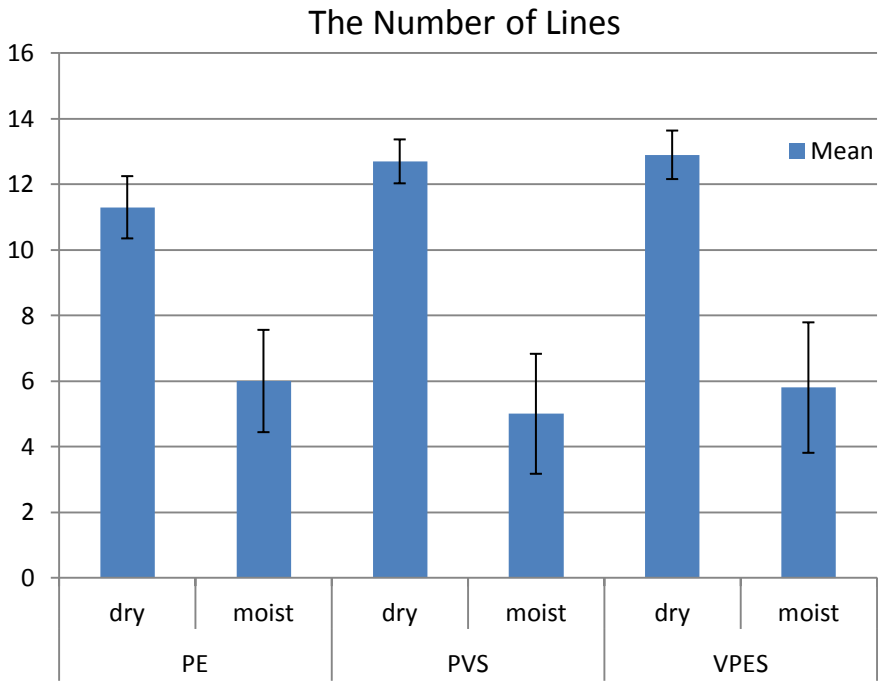

FIGURE 9. The number of lines reproduced in a detail reproduction test. There are significant differences among dry and moist conditions in PE, PVS, and VPES ($p < 0.0001$). There are significant differences among PE, PVS, PE, and VPES under dry conditions ($p = 0.0005$, $p = 0.0001$).

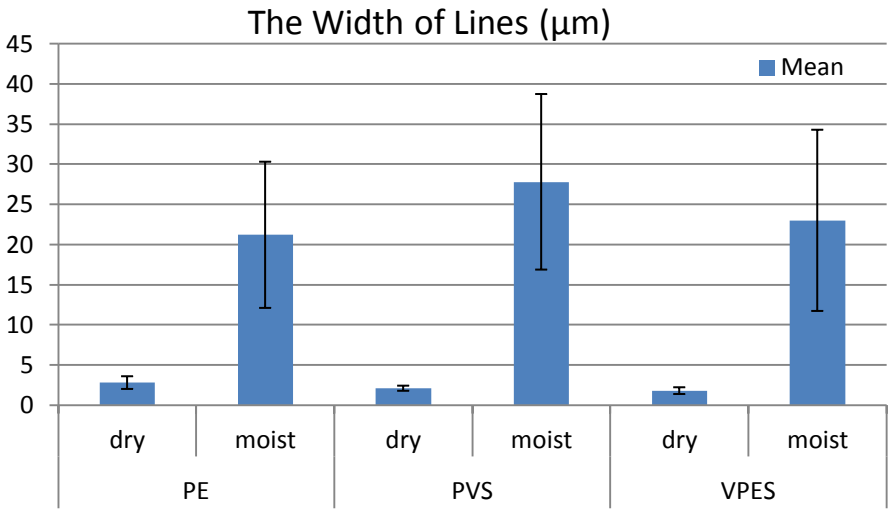

FIGURE 10. The width of lines reproduced in a detail reproduction test. There are significant differences among dry and moist conditions in PE, PVS, and VPES ($p < 0.0001$). There is no significant difference among PE, PVS, and VPES under dry conditions ($p = 0.41$).

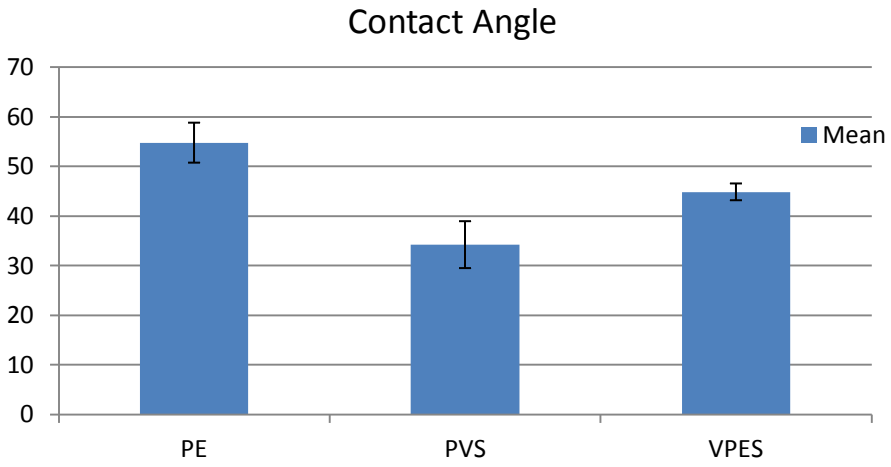

FIGURE 11. The contact angle of three materials. There are significant differences in contact angles among PE, PVS, PE and VPES, PVS, and VPES ($p < 0.0001$).

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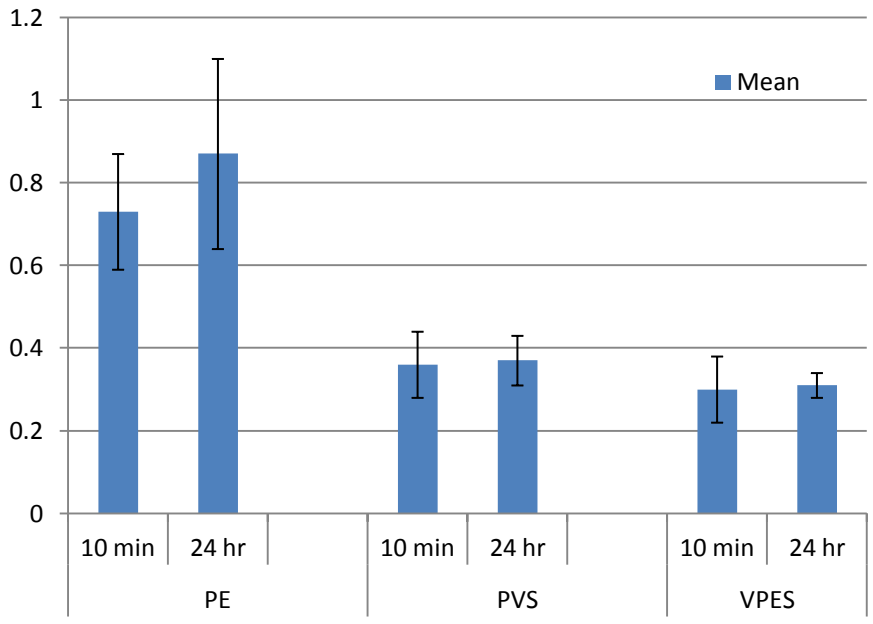

FIGURE 12. The tear strength of three materials. There are significant differences between 10-min and 24-h groups in PE, PVS, and VPES ($p = 0.0371$). There are significant differences between PE and PVS, PE and VPES, and PVS and VPES at 10 min and 24 h ($p < 0.0001$, $p < 0.0001$, $p = 0.0006$).

DISCUSSION

The methodology for investigating impression surface detail reproduction is varied. Some investigators have made impressions of a specimen with a rough surface pattern and visually graded the specimens or utilized a photograph of the surface under magnification;[1,66,67] some have poured the impression with a gypsum product and evaluated the detail of the cast;[41,68,69] and others have performed a subjective type of evaluation in which an impression is made and an examiner counts the number of voids on the surface under standardized light and at a standardized working distance.[19,70] The popular approach is to make impressions of a fine calibration standard that possesses known, uniform surface characteristics, and the impressions or resulting casts can then be assessed for reproduction of these fine surface characteristics.[71]

According to ADA Specification No. 19, elastomeric impression materials used to fabricate precision castings must be able to reproduce fine detail to a level of 20 µm or less.[66] In this study, an modified ISO standard metal die was employed to reduce the variables associated with the uncontrollable factors; thus the ability of the impression material to reproduce surface detail was assessed in an approach that was more precise and comparable. Previous studies have shown that detail reproduction is a major clinical consideration with a limiting factor in the system being the ability of gypsum die materials to replicate the fine detail. However, the corresponding specification for gypsum die materials requires replication of 50 µm, while the specification for impression materials is 20 µm. Most die materials do considerably better than this but fall far short of the impression materials in their ability to reproduce fine detail.[1] In order to

avoid the interferences from gypsum products in this study, the detail reproduction was directly evaluated from impressions made from the standard die instead of evaluating the casts generated from these impressions.

Based on the preliminary results from the pilot study, it revealed that in some impressions, there were areas of pits, voids, and roughness not associated with the horizontal lines used for evaluation. If such pits or voids were located on the preparation margin, the impression would be unacceptable.[19] Therefore, an additional microscopic evaluation of the width of lines may be beneficial and was applied in this study.

The results showed that all three materials produced better detail reproduction under the dry conditions than moist conditions, which suggested that the existence of moisture was an adverse factor that affected the detail reproduction. This conclusion is consistent with previous studies.[22,72,73]

Hydrophilicity has been regarded as one impression material property that affects the wetting of oral soft and hard tissues and correspondingly, this property affects the accurate detailed reproduction of prepared tooth surfaces.[8,18] In chemistry, hydrophilicity largely depends on the functional groups that the material contains. Polyether (PE) impression material is claimed by its manufacturer as more hydrophilic because of its functional groups [carbonyl (C = O) and ether (C-O-C)]. These polarized groups can attract and interact with water molecules; this interaction facilitates the contact between impression materials and moist oral tissues.[6,74] Conventional PVS behaves hydrophobically because it does not contain any polarized groups.[75] The incorporation of nonionic surfactants has been investigated to overcome this inherent hydrophobicity.[76,77] These surfactants act through a diffusion transfer of surfactant molecules from the surface

of PVS into the aqueous phase, and the surface tension of the liquid is then reduced.[42] As a result, hydrophilized PVS materials have been developed with improved wetting behavior. The chemistry structure of the new material VPES claimed by manufacturers is that the large molecular polyether chains form the backbone frames, and that the smaller PVS molecules attach onto the PE backbone. The existence of functional groups of PE can provide similar hydrophilic characteristics to PE.[74,78]

Although the impressions made under the moist condition were not as good as those made under the dry condition in this study, all of them met the requirements of the ISO standard. When assessed by the number of lines being reproduced, PE showed fewer lines than PVS and VPES under the dry condition (Table IV). However, with the more strict criteria used in this study, when assessed by the width of the lines reproduced (small up to 1 μm), the differences between them vanished (Table V). Some previous studies concluded that PE provided better detail reproduction than other elastomeric materials under moist conditions, while others claimed that PE showed no difference or less detail reproduction than hydrophilized PVS.[19,21-23] The results of this study suggest that the difference of evaluation criteria might be one of the sources of controversies in this field.

Beside the hydrophilicity, clinical studies have shown that the viscosity of the impression material is another important factor. The proper viscosity of materials in producing impressions is imperative for maximum detail impressions and dies with minimal bubbles.[42,79] Other factors that may influence surface detail reproduction are clinical situations that cause surface contamination, such as the presence of astringent or hemostatic agents used during tissue retraction or latex contamination.

There are limitations of this investigation. Given the impressions were made of standardized stainless steel dies, they do not resemble the behavior of the oral tissues. For example, metal dies do not absorb liquid.[80] In addition, the intrinsic free energy on the surface of a metal die will be much higher than the free energy of the proteinaceous surfaces of prepared teeth and oral soft tissues. The surface energy of the impressed surface will also affect how well the impression material will wet that surface.[77] Another limitation of this *in-vitro* study is that water instead of saliva was used as the source of moisture. It is well known that properties of saliva[81] are quite different than those of water, and these differences could potentially have affected the behavior of the impression materials.

However, in this laboratory study an attempt was made to reduce the variables associated with the differences of liquids; thus the ability of the impression material to reproduce surface detail was assessed in the presence or absence of water.

CONTACT ANGLE

The term hydrophilicity is related to two different aspects of the material. One aspect is related to the surface free energy and the associated wettability of the polymerized, solid impression material with the gypsum slurries.[9,14] The second aspect involves the surface free energy of the unpolymerized, liquid impression material and its ability to wet the impressed surface.[82]

This study concentrated on the first aspect. Although there is no clear evidence as to which inherent properties of a material might specifically affect its wetting ability,[13,83] the hydrophilicity of the set material is regarded as a major influencing factor to avoid the entrapment of air bubbles during die casting.[8,63] Therefore, the hydrophilicity of an

impression material may influence the die[44,72] and consequently affect the ultimate clinical success of a fixed prosthetic restoration.[39]

Pratten and Craig[84] stated that the strong negative linear correlation observed between the contact angle and the percent castability of the die stone indicates that contact angle measurement is a good predictor of the hydrophilicity of an impression material. and that a low value of a contact angle for an impression material corresponds to a small volume of voids. There is no standard accepted method for contact angle determination.[72,81] Different techniques may be used, such as sessile drops or the Wilhelmy method.[79] The sessile drop method is measured by a contact angle goniometer using an optical subsystem to capture the profile of a pure liquid on a solid substrate. The angle formed between the liquid/solid interface and the liquid/vapor interface is the contact angle. The Wilhelmy method is a method for measuring and calculating average contact angles on solids of uniform geometry as the solid is immersed in or withdrawn from a liquid of known surface tension.[40]

In this study, the sessile drop method was employed because it is regarded as an appropriate means of measurement to assess the hydrophilicity of impression materials.[13,73] In our investigation, the measurement was performed by the Pocket Goniometer model PG-2, which is a video-based instrument designed for qualified applications in quality control and research.

The result of this study showed that the VPES and the hydrophilic PVS showed much lower value of contact angle than PE. The mean contact angle of PE was 54.76º, which is consistent with other studies for its inherent hydrophilicity based on its chemical structure. This is consistent with previous studies.[68-70] The lowest contact angle was

found as low as 34.19º for the hydrophilized PVS in this study. However, the mechanism of this wettability is from the presence of surfactants in their composition, and this enhanced wettability can benefit more gypsum slurries than impressed surfaces.[44] The VPES, which can be regarded as a mixture of PE and PVS, showed a comparatively low contact angle 44.84º, which is lower than PE. This wettability is from its chemical structure as that in PE, which is important both for castibility and impressed surfaces.

In conclusion, the wettability of the new generation of impression material is superior to that of PE, and hydrophilized PVS has a lower contact angle than PE and VPES.

TEAR STRENGTH

The tear strength was tested by the trouser tear test in this study. Two setting times were examined: 1) immediately after setting 10 min, and 2) 24 h after setting. The 10-min testing imitates removal from the patient's mouth, and the 24-h testing mimics the cast's removal from the impression. Shorter setting times for impression materials are more convenient for clinicians, particularly when a single tooth has been prepared.[12] If the manufacturer's suggested set time is not accurate and if the impression material has not completely polymerized before removal, the impression material will tear.[52,65]

The data showed that the improved tear strength of all three materials was found in 24-h groups (Table VII). This suggested that the polymerization of these impression materials continued even after doubling the setting time recommended by the manufacturer. At both setting times, PE consistently showed a tear strength that was two times higher than PVS and VPES. This result was consistent with previous studies that showed polyether to have higher tear strength than PVS.[20] The VPES material exhibited

the slightly lower tear strength compared with the PVS. Whether this relative lower tear strength can cause the tearing of impression material needs further study, when techniques involve impressing intraorally, or when separating from casts.

A limitation of this study was that other important properties influencing the tear strength, including the flow characteristics of the material, adhesion to the teeth and soft tissues, and the presence of internal and surface defects were not assessed. Regarding flow and adhesion, some materials flow more readily into the sulcus than others, resulting in a thinner film, and tear strength is directly related to film thickness.[85] In addition, propagation of a tear must be preceded by initiation. These sites of tear initiation could result from internal and surface defects within the polymerized material.[86] The relative level of hydrophilicity or hydrophobicity of the different materials may affect the interactions between the material and blood or tissue fluids in the sulcus. The incorporation of these fluids during polymerizing could result in defects which, acting as stress initiators, may ultimately reduce the tear strength of the polymerized material.[82]

SUMMARY AND CONCLUSIONS

This *in-vitro* study was conducted to evaluate and compare performance of the new impression material VPES with the current commonly used PE and hydrophilic PVS in detail reproduction, contact angle, and tear strength.

The study was divided into three parts:

1) Detail reproduction: to compare VPES to PE or PVS in detail reproduction under dry and moist conditions.

2) Contact angle: to compare VPES to PE or PVS in wettability by measuring the angle at which a liquid/vapor interface meets an impression material surface.

3) Tear strength: to compare VPES to PE or PVS in tear strength after 10 minutes and 24 hours.

The findings of this study can be summarized as follows:

DETAIL REPRODUCTION

All three impression materials showed better detail reproduction under dry conditions when compared with moist conditions. This result confirmed that the existence of moisture was an adverse factor for making an impression. When evaluated by measurement of the width of reproduced lines, PVS, VPES, and PE showed no difference in detail reproduction both under the dry conditions and moist conditions. All three materials produced acceptable impressions both under dry and moist conditions according to the requirements of ISO 4823.

The conclusion supports the assertion that moisture control is of critical importance for a good impression even when naturally hydrophilic or hydrophilized materials are used. The new impression material showed comparable properties in detail reproduction to PE and PVS under dry or moist conditions.

TEAR STRENGTH

The tear strength in the 24-h groups was significantly higher than those in the 10-min groups. This suggests that the polymerization was still going on after 10 min of setting, which was double the recommend time from the manufacturer. The tear strength of PE was significantly higher than that of PVS or VPES. The tear strength of PVS was slightly higher than VPES.

The conclusion is that the PE has higher tear strength than PVS and VPES. VPES has slightly lower tear strength than PVS.

CONTACT ANGLE

Hydrophilized PVS showed better wettability when tested by a pocket goniometer. The contact angle was as low as 34.19º for hydrophilic PVS. This suggests that the surfactant was enhancing the wettability of the PVS and resulted in a lower contact angle. The contact angle of PE was 54.76º, which is consistent with previous studies. The contact angle of the new impression material VPES was 44.84º, which was lower than PE. This enhanced wettability of VPES will render more accurate impressions and fewer voids or bubbles in the casts.

The conclusion is that the PVS with surfactant has better wettability than PE and VPES. The new impression material VPES exhibited a better wettability than PE.

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APPENDIXES

APPENDIX I

Raw data for detail reproduction test

	Dry			Moist		
	PE	PVS	VPES	PE	PVS	VPES
Sample 1	12	11	12	7	F	F
Sample 2	11	13	14	F	6	9
Sample 3	13	12	13	8	F	8
Sample 4	12	13	13	6	F	F
Sample 5	11	13	12	F	7	7
Sample 6	11	13	13	8	F	6
Sample 7	10	13	14	7	F	F
Sample 8	11	13	13	F	7	7
Sample 9	12	13	12	6	F	F
Sample 10	10	13	13	6	8	6
Average	11.3	12.7	12.9			

'F' samples failed to reproduce 20-µm line.

APPENDIX II

Raw data for contact angle test (PE)

	PE 1	PE 2	PE 3	PE mean
Sample 1	57.4	59.4	58.1	58.3
Sample 2	58.8	58	56.4	57.7
Sample 3	57.9	57.3	56.9	57.4
Sample 4	51.9	54.2	54.4	53.5
Sample 5	48.9	52.9	55.5	52.4
Sample 6	53.3	50.7	50.5	51.5
Sample 7	55.1	53.2	49.6	52.6
Sample 8	53.1	50.3	47.9	50.4
Sample 9	51.1	49.7	50.2	50.3
Sample 10	51.5	49.1	51.4	50.7
Sample 11	50.1	49.9	55.7	51.9
Sample 12	56.1	56	52.1	54.7
Sample 13	62.3	61.5	62.5	62.1
Sample 14	61.1	61.6	60.8	61.2
Sample 15	59.9	60.7	60.2	60.3
Sample 16	59.2	60.8	60.3	60.1
Sample 17	59.9	60.7	59.1	59.9
Sample 18	62.9	56.8	60.9	60.2
Sample 19	55.1	51.8	54.6	53.8
Sample 20	56.3	53.3	52.5	54.0
Sample 21	49.5	51.4	50.2	50.4
Sample 22	50.4	52.6	49.8	50.9
Sample 23	49.7	52.1	51.9	51.2
Sample 24	54	50.9	49.2	51.4
Sample 25	53.4	49	53.5	52.0
Average				54.8

APPENDIX III

Raw data for contact angle test (PVS)

	PVS 1	PVS 2	PVS 3	PVS mean
Sample 1	32.4	30.7	33.6	32.2
Sample 2	33.8	29.9	32.4	32.0
Sample 3	40.4	42.2	36.5	39.7
Sample 4	24	34	25	27.7
Sample 5	29.2	41.3	34	34.8
Sample 6	35	38.6	34.3	36.0
Sample 7	31.5	32	27.1	30.2
Sample 8	31	37.4	32.4	33.6
Sample 9	32.4	33	26.6	30.7
Sample 10	30.9	26.3	28.4	28.5
Sample 11	31.1	30.4	34.9	32.1
Sample 12	24.1	23.2	36.6	28.0
Sample 13	38.9	40.2	36.6	38.6
Sample 14	43.7	43	32.3	39.7
Sample 15	32.7	32	34.6	33.1
Sample 16	37.6	38.9	47.4	41.3
Sample 17	37.7	39.6	39	38.8
Sample 18	46.2	39.6	38.5	41.4
Sample 19	25.6	21.7	25.6	24.3
Sample 20	36.5	29.4	29.6	31.8
Sample 21	32	34.6	41	35.9
Sample 22	30.3	30.1	38.6	33.0
Sample 23	25.2	39.9	30.7	31.9
Sample 24	46.8	36.9	36.7	40.1
Sample 25	37.9	38.7	41.5	39.4
Average				34.2

APPENDIX IV

Raw data for contact angle test (VPES)

	VPES 1	VPES 2	VPES 3	VPES mean
Sample 1	44.9	42	41.7	42.9
Sample 2	43.6	43	43.3	43.3
Sample 3	45.6	42.1	38.7	42.1
Sample 4	44	42.3	44.5	43.6
Sample 5	45	44.5	47	45.5
Sample 6	44	43.1	48.3	45.1
Sample 7	45.8	43.8	42.6	44.1
Sample 8	46.3	45.9	47.8	46.7
Sample 9	48.1	45.6	46.1	46.6
Sample 10	45.3	45.1	48.3	46.2
Sample 11	46.7	43.5	41.9	44.0
Sample 12	45.7	44.1	45.3	45.0
Sample 13	44.4	45.2	47.7	45.8
Sample 14	44	38.3	39.3	40.5
Sample 15	46.5	45	45.4	45.6
Sample 16	45.8	44	48.5	46.1
Sample 17	45.2	42.2	39.1	42.2
Sample 18	45.7	45	44.7	45.1
Sample 19	47	46.1	44.3	45.8
Sample 20	42	44.5	49.2	45.2
Sample 21	45.9	44.3	48.3	46.2
Sample 22	44.4	43.8	43.7	44.0
Sample 23	42	48.3	45	45.1
Sample 24	47.9	46.9	48	47.6
Sample 25	50	44.9	45.2	46.7
Average				44.8

APPENDIX V

Raw data of tear strength test (PE-10 min)

Specimen#	Peak Load	Linear Load at Tear N/mm	Peak Load N
1	0.807	0.769	0.807
2	0.838	0.813	0.838
3	0.739	0.684	0.739
4	0.882	0.865	0.882
5	0.635	0.599	0.635
6	1.046	1.016	1.046
7	0.632	0.585	0.632
8	0.856	0.832	0.856
9	1.003	0.993	1.003
10	0.606	0.566	0.606
11	0.639	0.609	0.639
12	0.690	0.676	0.690
13	0.651	0.626	0.651
14	0.662	0.656	0.662
15	0.700	0.667	0.700
Mean	0.759	0.730	0.759
Std. Dev	0.140	0.144	0.140
% COV	18.45	19.77	18.45
Minimum	0.606	0.566	0.606
Maximum	1.046	1.016	1.046

APPENDIX VI

Raw data of tear strength test (PVS-10 min)

Specimen#	Peak Load	Linear Load at Tear N/mm	Peak Load N
1	0.322	0.315	0.322
2	0.217	0.217	0.217
3	0.338	0.341	0.338
4	0.507	0.478	0.507
5	0.390	0.378	0.390
6	0.320	0.323	0.320
7	0.278	0.270	0.278
8	0.371	0.340	0.371
9	0.517	0.507	0.517
10	0.401	0.401	0.401
11	0.351	0.344	0.351
12	0.407	0.407	0.407
13	0.327	0.306	0.327
14	0.400	***	0.400
15	0.472	0.433	0.472
Mean	0.375	0.362	0.375
Std Dev	0.082	0.079	0.082
% COV	21.88	21.82	21.88
Minimum	0.217	0.217	0.217
Maximum	0.517	0.507	0.517

APPENDIX VII

Raw data of tear strength test (VPES – 10 min)

Specimen#	Peak Load	Linear Load at Tear N/mm	Peak Load_N
1	0.216	0.220	0.216
2	0.245	0.255	0.245
3	0.229	0.229	0.229
4	0.358	0.373	0.358
5	0.291	0.294	0.291
6	0.235	0.235	0.235
7	0.268	0.279	0.268
8	0.256	0.254	0.256
9	0.465	0.495	0.465
10	0.258	0.253	0.258
11	0.255	0.253	0.255
12	0.417	0.430	0.417
13	0.280	0.280	0.280
14	0.317	0.324	0.317
15	0.262	0.273	0.262
Mean	0.290	0.296	0.290
Std Dev	0.071	0.079	0.071
% COV	24.59	26.51	24.59
Minimum	0.216	0.220	0.216
Maximum	0.465	0.495	0.465

APPENDIX VIII

Raw data of tear strength test (PE – 24 h)

Specimen#	Peak Load	Linear Load at Tear N/mm	Peak Load N
1	0.897	0.879	0.897
2	1.087	1.076	1.087
3	0.991	0.972	0.991
4	0.798	0.783	0.798
5	0.882	0.822	0.882
6	1.492	1.478	1.492
7	0.904	0.913	0.904
8	1.068	1.068	1.068
9	0.597	0.609	0.597
10	0.806	0.806	0.806
11	0.472	0.482	0.472
12	0.742	0.749	0.742
13	0.985	0.985	0.985
14	0.855	0.799	0.855
15	0.725	0.703	0.725
Mean	0.883	0.875	0.883
Std Dev	0.237	0.232	0.237
% COV	26.79	26.56	26.79
Minimum	0.472	0.482	0.472
Maximum	1.492	1.478	1.492

APPENDIX IX

Raw data of tear strength test (PVS – 24 h)

Specimen#	Peak Load	Linear Load at Tear N/mm	Peak Load N
1	0.391	0.387	0.391
2	0.262	0.250	0.262
3	0.430	0.426	0.430
4	0.441	0.441	0.441
5	0.290	0.281	0.290
6	0.336	0330	0.336
7	0.326	0.333	0.326
8	0.388	0.384	0.388
9	0.456	0.447	0.456
10	0.330	0.334	0.330
11	0.429	0.405	0.429
12	0.501	0.477	0.501
13	0.398	0.372	0.398
14	0.413	0.390	0.413
15	0.378	0.353	0.378
Mean	0.385	0.374	0.385
Std Dev	0.065	0.062	0.065
% COV	16.98	16.67	16.98
Minimum	0.262	0.250	0.262
Maximum	0.501	0.477	0.501

APPENDIX X

Raw data of tear strength test (VPES – 24 h)

Specimen#	Peak Load	Linear Load at Tear N/mm	Peak Load N
1	0.333	0.333	0.333
2	0.336	0.333	0.336
3	0.296	0.296	0.296
4	0.291	0.297	0.291
5	0.272	0.287	0.272
6	0.283	0.285	0.283
7	0.313	0.323	0.313
8	0.284	0.287	0.284
9	0.297	0.297	0.297
10	0.281	0.290	0.281
11	0.249	0.247	0.249
12	0.365	0.380	0.365
13	0.371	0.367	0.371
14	0.312	0.321	0.312
15	0.303	0.303	0.303
Mean	0.306	0.310	0.306
Std Dev	0.034	0.034	0.034
% COV	11.01	11.00	11.01
Minimum	0.249	0.247	0.249
Maximum	0.371	0.380	0.371

ABSTRACT

LABORATORY EVALUATION OF TEAR STRENGTH, CONTACT ANGLE, AND DETAIL REPRODUCTION OF THREE ELASTOMERIC IMPRESSION MATERIALS

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Fabrications of desirable fixed or removable dental prostheses depend upon accurate casts or dies. Recently, the most frequently used impression materials have been polyether (PE) and polyvinyl siloxane (PVS). However, both have their limitations: PVS is inherently hydrophobic, and PE is rigid. In order to take advantage of the desirable qualities of both PVS and PE impression materials, a new generation of impression material is being developed called vinyl polyether silicone (VPES, GC).

The purpose of the present study was to compare the properties of hydrophilic PVS, PE, and VPES in regard to surface detail reproduction, contact angle, and tear strength. The hypotheses to be tested were: 1) VPES will show a significant superiority in

surface detail reproduction compared with PVS and PE impression materials; 2) VPES will show a significant superiority in wettability compared with PVS and PE impression materials; 3) VPES will show a significant superiority in tear strength compared with PVS and PE impression materials.

In order to test the surface detail reproduction, impressions were made of stainless steel dies with a parallel series of 15 different width lines on the surface and tested under dry and moist conditions. The wettability was assessed by contact angles of saturated $CaSO_4$ aqueous solution drops on flat impression surfaces. A trouser tear test was employed to test the tear strength. The trouser-shaped specimens were prepared and tested in the Instron Universal Testing Machine. The data were analyzed by one-way ANOVA and Pearson's Chi square, ($p < 0.05$).

All the materials showed better detail reproduction under the dry conditions than the moist conditions. There were no differences between the three materials in detail reproduction when impressing under either moist conditions or dry conditions. All the materials showed good wettability in the contact angle test. PVS rendered a contact angle as low as 34.19º. The contact angle of VPES was 44.84º, which was lower than 54.76º for PE. In the tear strength test, PE showed nearly two time higher tear strength than the other two impression materials. VPES showed slightly lower tear strength than PVS. The tear strength of the three materials tested in increasing order was VPES, PVS, PE.

VPES showed comparable detail reproduction to PVS and PE and better wettability than PE, but showed the lowest tear strength compared with PE and PVS.

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